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A WSN-Based System for Environment Monitoring and Energy Saving Control in Hull Workshop

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Abstract: In the shipbuilding process, lighting system in hull workshop consumes a large amount of electricity and the temperature and humidity inside affect the safety and quality of production directly. In order to save energy and monitor the temperature and humidity of working space in real time, an environment monitoring and energy saving control system was designed based on ZigBee wireless sensor networks. By locating workers' coordinates, the corresponding lighting devices are on-off automatically. The temperature and humidity are adjusted automatically by analyzing and processing the real-time temperature and humidity data sent from monitoring nodes. The test results in hull workshop show that the average location error is less than 1.2 m and the energy saving is also effective. *Copyright © 2013 IFSA.*

Keywords: ZigBee WSN, Hull workshop, Staff position, Lighting energy-saving, Automatic control of temperature and humidity.

1. Introduction

With the rapid development of shipbuilding industry, the competition becomes increasingly fierce. Ensuring the safety of staves and producing, improving the quality of production and reducing costs have become the main ways for shipyards to enhance their competitiveness. For shipyard, energy costs have become the third largest expenditure following materials and equipment costs and labor costs, presenting a growing trend. And among those electricity costs takes up more than 40 % [1]. In the process of shipbuilding, a lot of lighting devices are needed in hull workshop as ship is a relatively independent and enclosed area. However, currently most of cabin lighting equipments are controlled by workers. As a result most of the lamps keep working all the time even when staffs stop working, which leads to a huge amount of waste. Therefore, lighting should never be underestimated among the energy-using units of electric equipment in shipyards. In addition, welding is an indispensable key technology to modern shipbuilding. Temperature and humidity in welding materials repository should be effectively controlled in a level where the indoor temperature is no less than 5 ºC and relative air humidity there is no higher than 60 %. And desiccant is needed to prevent welding materials from getting damp. Therefore, the quality of welding is directly related to proper control of temperature and humidity. After welding, painting operation is needed. Xylene and rosin water are often used thinner of internal coating and antirust paint, whose flashpoint are all below 28°C belong to first-class dangerous flammable materials. After diluted, paint will be atomized through air pump pressure by the spray gun. The produced volatile gas is combustible gas which easily explodes when there are open flames. So in case of explosion hazard, the temperature in painting operations workshop must be strictly controlled. At present, however, temperature and humidity are simply inspected by thermometer and hygrometer, having no any effective regulation in sensitive areas. It is urgent to implement intelligent control on energy saving and temperature and humidity monitoring in real time.

One of the intelligent lighting devices that save power is Pyroelectric Infrared Sensor. It responds by detecting the strength changes of the infrared radiated by body. It is susceptible to various sources of heat and light interference. In addition, the sensitivity is closely related to the moving direction of forks [2]. The two points mentioned above cannot meet the requirements of workers who work on circulating freely and doing jobs which produce heat such as welding. Another is Microwave Radar Sensor Switch. Adopting microwave radar principle of Doppler, it can implement the function of switch control by monitoring body movement. The switch is not affected by ambient temperature and the movement direction of human body, but its window is easily shielded and interfered by mental, and it is also easily affected by electromagnetic wave around, resulting in false action. Besides, both of the sensors must be installed in workshop field, for switching response can generate electric spark which easily leads to danger by igniting the combustible gas in cabin.

ZigBee is a kind of bidirectional wireless network technology with low power consumption, low-data-rate, low complexity, low-cost and short-range [3]. It could be embedded in all kinds of devices, support in-door Geo-location function, achieve precise positioning of a moving target and high quality wireless transmission of data in real time. And it is used widely in area of industrial monitoring, safety system, smart home, etc [4]. The functions and advantages of the ZigBee technology can meet the specific environmental requirements of hull workshop and overcome the shortcomings of the two switches mentioned above. In this paper, a ZigBee-based system for environment monitoring and energy saving control in hull workshop is designed, which can be applied in the process of shipbuilding. A wireless network is established in three-dimensional space in cabin by ZigBee wireless sensors. By locating workers' coordinates, lights will be on whenever workers come; lights will be off as soon as people leave. Temperature and humidity are monitored by ZigBee End Devices embedded temperature and humidity sensor in real time to be at appropriate level. At the same time, through computer monitoring software it implements headcount in cabin, displaying the in-out time and checking on work attendance.

2. System Architecture

The system consists of Temperature and Humidity Acquisition Module, ZigBee Wireless Positioning Module, Central Processing Unit and Control Module, as shown in Fig. 1. Central Processing Unit receives coordinates of workers from Wireless Positioning Module and the real-time temperature and humidity value of monitored area from Temperature and Humidity Acquisition Module. After analyzed and proceeded, the effective information is transmitted to Control Module. Control Module then sends corresponding control commands to drive loads.

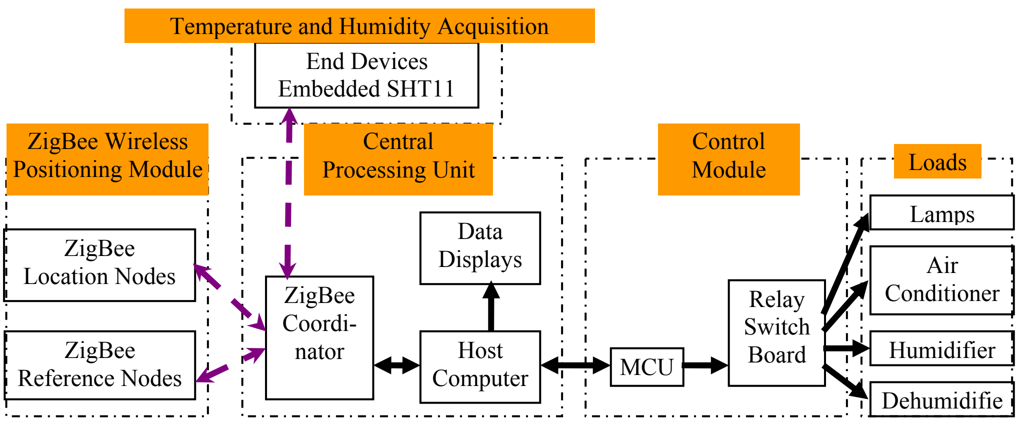

Fig. 1. Hardware composition block diagram of the system.

2.1. Design of Each Module

ZigBee Wireless Positioning Module includes a ZigBee coordinator, eight reference nodes and a number of positioning nodes (staves wear). Coordinator is the initiator of ZigBee wireless network, which mainly works on the establishment, configuration and maintenance of network. After network established, Coordinator will have the same function with router. Reference Node is the static node with known coordinates in a wireless positioning system. It provides an information packet that contains its own X, Y coordinates and the received signal strength indicator (RSSI) value to Location Node. Location Node is a mobile node in positioning system, which calculates its own coordinates by the known coordinates of Reference Node [4]. Coordinator and Reference Nodes are all composed of CC2430 chip produced by TI and the corresponding peripheral circuits. Location Node uses the CC2431 chip. In addition to all hardware features of CC2430, the CC2431 includes a “Location Engine” Based on RSSI technology the CC2431 wireless location engine needs no additional hardware and data exchange. And it takes advantages of higher speed, higher precision and doesn’t consume the CPU’s resources compared with software localization [5].

Firstly, node localization uses the location algorithm based on RSSI – the simplified Shadowing model [6] to determine the distance from Location Node to Reference Node. Then the position of Location Node is calculated by using Trilateration [7]. To improve location accuracy, Trilateration optimization algorithm – Cooperative Location Estimation [7] is used. Two algorithms are well introduced in [7].

CC2431 on-chip location engine calculates the position of a Location Node based on RSS and the coordinates of Reference Nodes. Location principle model as shown in Fig. 2, computer software established a two-dimensional XY place within the coverage area of the wireless network. Rectangle in the figure represents Reference Node and the small ball represents Location Node.

After ZigBee Location Node entered the wireless network, it sends out a blast of broadcast messages for RSSI packets immediately to the adjacent Reference Nodes. Any Reference Nodes receiving such a message shall make a running average of the RSSI of the packets received from a particular Location Node. Then Reference Nodes send the average value and their own coordinates to the Location Node. Location Node puts down the information and input parameters (A, n) into the Location Engine and calculates the distance to each Reference Node. Finally, Location Node calculates its own position by using the algorithm above according to the distance to Reference Node and coordinates of Reference Node and transmits it to Coordinator to complete the positioning.

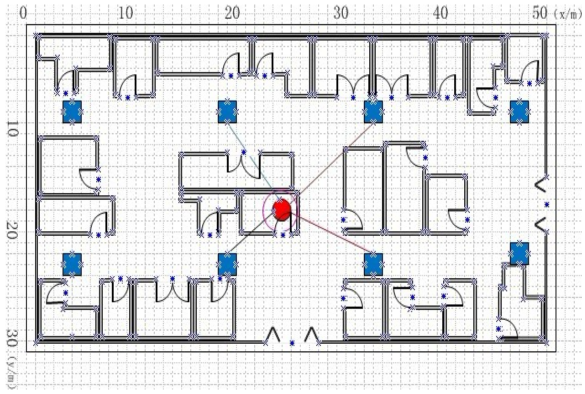

Fig. 2. Location principle model of ZigBee wireless network.

Because of the system, which needs to get coordinates of workers to turn on the corresponding lighting device, higher request on location accuracy is requested. Localization algorithm optimization, hardware selection, debugging strategy, configuration of environmental parameters and so on all are aimed at improving the positioning accuracy to meet the actual requirements of this application.

Temperature and Humidity Acquisition Module is composed of ZigBee End Device embedded SHT11 digital temperature and humidity sensor. End Devices, mainly responsible for wireless data collection, need to join the network which has been established without network maintenance function [8].

SHT11 is a new digital relative humidity and temperature sensor based on CMOSense technology of Sensirion company. The sensor can be used to measure relative humidity, temperature and dew point. Applied CMOSense technology guarantees excellent reliability and long term stability. Typical resolutions of measured temperature and relative humidity are 14 bit and 12 bit [9]. Technical parameters of SHT11 are shown in Table 1.

Table 1. Technical parameters of SHT11.

Measured Parameter	Operating Range	Resolution	Accuracy	Average Power Consumption
Temperature	-40~123.8 °C	0.01 °C	±0.4 °C	90 µW
Relative Humidity	0~100 %RH	0.05 %RH	±3.0 %RH	Low Consumption

Central Processing Unit is composed of PC, IAR EW8051 and TI Z-Location Engine monitoring software. The parameters of reference nodes and locating nodes can be configured and queried by the monitoring software wirelessly. In addition, the computer software with expanded functions is developed through IAR EW8051 and TI Z-Location Engine. It is used to analyze and proceed the real-time data monitored by hardware devices to realize headcount in cabin, displaying the in-out time and checking on work attendance.

Control Module consists of STC89C52 MCU development board with two serial ports and relay switch board integrated 16 ones. Between the two serial ports, one is a hardware serial port and the other is full duplex serial sequence of software simulation with the same function of data communication. Board-level address of relay switch board is 8 bit, which can be set to address 1-255. 255 boards can be connected to a bus, and 255*16=4080 relay control nodes are available at the same time without any influence on each other. Each output has LED indicator. When relay is closed and LED begins to shine, which means power load. Otherwise, relay is disconnected and the light is out.

2.2. Operation Principle and Process

Coordinator will search for the best channel after the system is powered on. Then it broadcasts networking message to all nodes with sending Personal Area Network Identity (PAN ID) of the network. After that it listens to network connecting requests of nodes at regular time. When receiving request, Coordinator will make a judgment before allowing the node join the network according to the request information. If allowed to join, the node can get a reply and a network address as the unique identity. Finally, Coordinator maintains the entire network by sending relevant control commands to child nodes periodically [10].

When a worker wearing Location Node enters the wireless network, Location Node communicates with the Reference Nodes nearest, collecting *X*, *Y* and RSSI values of these nodes. Then Location Node uses location engine to calculate its position based on the collected parameters. The position is transmitted to Coordinator wirelessly. End Devices embedded SHT11 drive SHT11 to collect temperature and humidity data. End Devices then transmit the real-time data to Coordinator in the form of data packets wirelessly. Coordinator transmits coordinate and temperature and humidity values of each monitored area to PC software by serial line. PC software is responsible for final data analysis. Workflow diagram is shown in Fig. 3.

PC software determines which lamps need to be turned on, or turned off according to the worker's coordinate. By comparing the real-time temperature and humidity values and warning limits, it identifies monitoring regional air conditioners, humidifiers and dehumidifiers turned on or off. Besides, because of different network address among the End Devices, number of people entering and leaving the cabin, in-out time, staff position coordinates, illuminated area and monitored real-time temperature and humidity data can be shown on visual interface. Loads switch information compiled by software is transmitted to MCU by serial line. And then Relay Board gets control messages compiled by MCU based on the communication protocol between MCU and Relay Board and sent by serial line to take switching action.

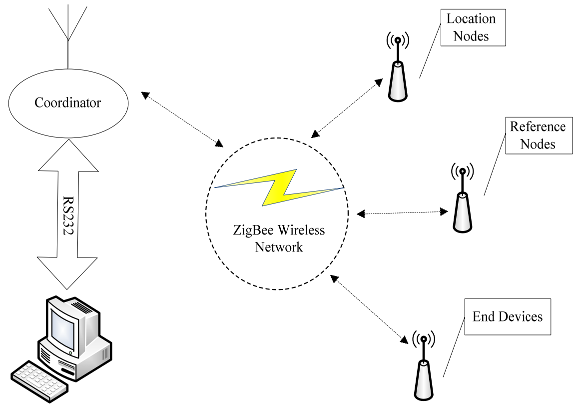

Fig. 3. Workflow Diagram of ZigBee Sensor Network.

3. Installing Testing and Results Analysis

The installation of Reference Nodes often depends on the coverage area of network and the transmission distance between each node which determines the number and the layout area (8 ones are used in this paper). All nodes are placed on the same plane as best as possible. Install the integrated development environment of IAR EW8051. Parameters of all Reference Nodes can be configured wirelessly by Z-Location Engine PC Application. Enter the coordinates of each Reference Node [*x*0, *y*0; *x*1, *y*1; …; *x*7, *y*7] (some can be set as the Origin) to establish a two-dimensional coordinates, which lock the coverage area of wireless network. Set a Reference Node and turn it on, which contributes to set position. ZigBee End Devices embedded SHT11 should be positioned in places where are sensitive to temperature and humidity based on specific environment in hull workshop. Because of low power consumption of all nodes, No. 5 battery of ordinary type can last several months. RS232 serial lines are used to connect Coordinator and PC, PC and MCU control board, MCU and relay board to be responsible for data communication. Outputs of relay board are directly connected with loads such as lamps, air conditioners and so on.

Switch on Coordinator and End Devices. Few seconds later, if Coordinator LED light flashes, it indicates that Coordinator has received the data sent by the End Devices and that a wireless network is established. Firstly, Coordinator will receive configuration information of each End Device provided by the monitoring software, and send it to corresponding nodes; Secondly, Coordinator will receive valid feedback data in each node and transmit it to monitoring software [3]. After Location Nodes entered the network and appeared on the display region of the monitoring software, place it on each of Reference nodes then adjust the parameters *A* and n to improve locating accuracy. The parameter *A* is defined as the absolute value of the average power in dBm received at a close-in reference distance of one meter from the transmitter, assuming an omni-directional radiation pattern. The *n* is defined as the path loss exponent that describes the rate at which the signal power decays with increasing distance from the transmitter [5]. In addition to Reference nodes, Location Node moving is visible and the network address and the real-time coordinates are also displayed in the interface. The refresh rate of locating coordinates is available to be modified. The debugging of Positioning Module is finished. MCU sends the command of turning on and off one by one to the 16 relays. If see each output LED indicator twinkles in turn, it indicates that the two boards work fine. The debugging is completed.

8 reference nodes were arranged in a cabin space with 16.5 m length and 5 m width. After repeated measurements parameters A and n are determined as *A* is 39, *n* is 25. Table 2 gives the location results and errors.

Table 2. Location result and error.

Real Coordinates (m)	Location Coordinates (m)	Absolute Error (m)	Location Error (m)
(5.0, 0.0)	(5.50, 0.75)	(0.50, 0.75)	0.90
(3.3, 7.0)	(4.25, 6.25)	(0.95, 0.75)	1.21
(1.8, 6.6)	(2.25, 5.75)	(0.45, 0.85)	0.96
(4.0, 2.0)	(4.75, 3.00)	(0.75, 1.00)	1.25
(2.0, 3.5)	(2.00, 4.50)	(0.00, 1.50)	1.00
(2.5, 8.0)	(3.25, 8.75)	(0.75, 0.75)	1.06
(4.4, 5.0)	(3.75, 6.00)	(0.65, 1.00)	1.19
(5.0, 16.5)	(4.75, 15.75)	(0.25, 0.75)	0.79
(3.0, 10.5)	(3.75, 10.00)	(0.75, 0.50)	0.90
(1.0, 12.0)	(1.25, 10.50)	(0.25, 1.5)	1.52

Table 2 shows that the average location error is less than 1.2 m which meets practical demand. The sources of error can be divided into three main categories:

1) The effect of environment: Reference Nodes are not often on the same plane strictly. Barrier, existing in the wireless environment, can lead to multipath fading. And the multipath may greatly affect the received signal strength. The mobility of the Location Nodes causes a dynamic change in the fading channel and makes it harder to compensate for the fading effect.

2) Hardware-related errors: Transceivers built for short-range and low-cost wireless networking have only a simple output power control mechanism. Besides the radiation pattern of an antenna is not omnidirectional and the transmitted signal strength at different directions may vary considerably. After manufactured the hardware will bring with natural error.

3) The limitations of the location-estimation algorithm itself: Received signal strength is quantized to form RSSI, so quantization will be an unavoidable source of error.

4. Conclusions

A kind of environment monitoring and energy saving system for cabin workshop is proposed based on ZigBee wireless sensor network. The system takes advantage of ZigBee wireless networking and positioning technology. By monitoring real-time coordinates of workers in cabin and values of temperature and humidity with the co-working of MCU and relay control board, it can implement that only in specific places of working with workers the lighting devices turn on. When temperature and humidity values deviated from the normal range, it begins to work automatically to keep them in appropriate level. In this way the goals of energy-saving, intelligent control and safe production can be achieved. Besides, real-time control of workers` coordinates contributes to improve the efficiency of management. This system is a modular structure with convenient installation, simple debugging and can be placed on different sizes of cabin space. Installed in the cabin for the actual test, it operates stably and works in good condition.

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